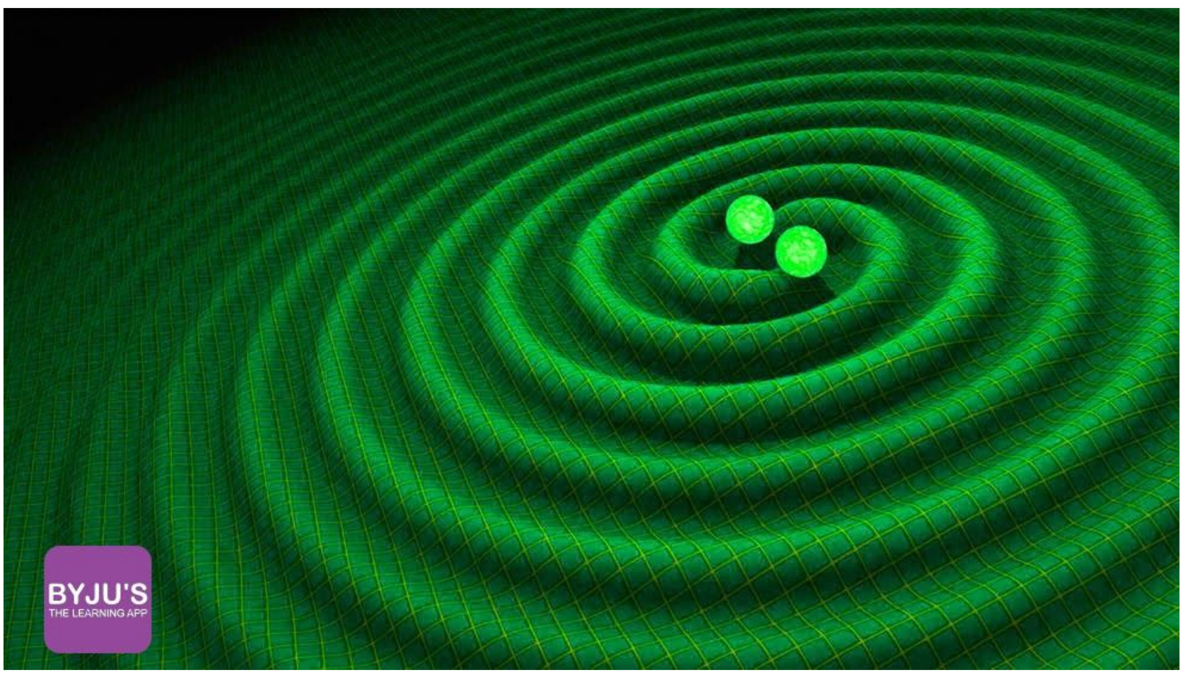
Gravitational Waves: UPSC Notes for Science and Technology

Gravitational waves are disturbances in the curvature of spacetime caused by accelerated mass. This concept is featured in the science and technology section of the UPSC Exam.

What are Gravitational waves?

- Gravitational waves are 'ripples' in the fabric of space-time caused by some of the most violent and energetic processes in the Universe.
- When an object accelerates, it creates ripples in space-time, just like a boat causes ripples in a pond.
- These space-time ripples are gravitational waves. They are extremely weak so are very difficult to detect.



- Two objects orbiting each other in a planar orbit such as a planet orbiting the Sun or a binary star system or the merging of two black holes will radiate Gravitational waves.
- Albert Einstein predicted the existence of gravitational waves in 1916 in his general theory of relativity.
- Einstein's mathematics showed that massive accelerating objects (such as neutron stars or black holes orbiting each other) would disrupt space-time in such a way that 'waves' of distorted space would radiate from the source.

- Furthermore, these ripples would travel at the speed of light through the Universe.
- G- Waves can pass through any intervening matter without being scattered significantly.
- While light from distant stars may be blocked out by interstellar dust, gravitational waves will pass through essentially unimpeded. This feature allows G-Waves to carry information about astronomical phenomena never before observed by humans.
- Colliding black holes send ripples through spacetime that can be detected on Earth. The Advanced Laser Interferometer Gravitational-Wave Observatory, or Advanced LIGO, which has detectors in Louisiana and Washington, has directly observed these gravitational waves.

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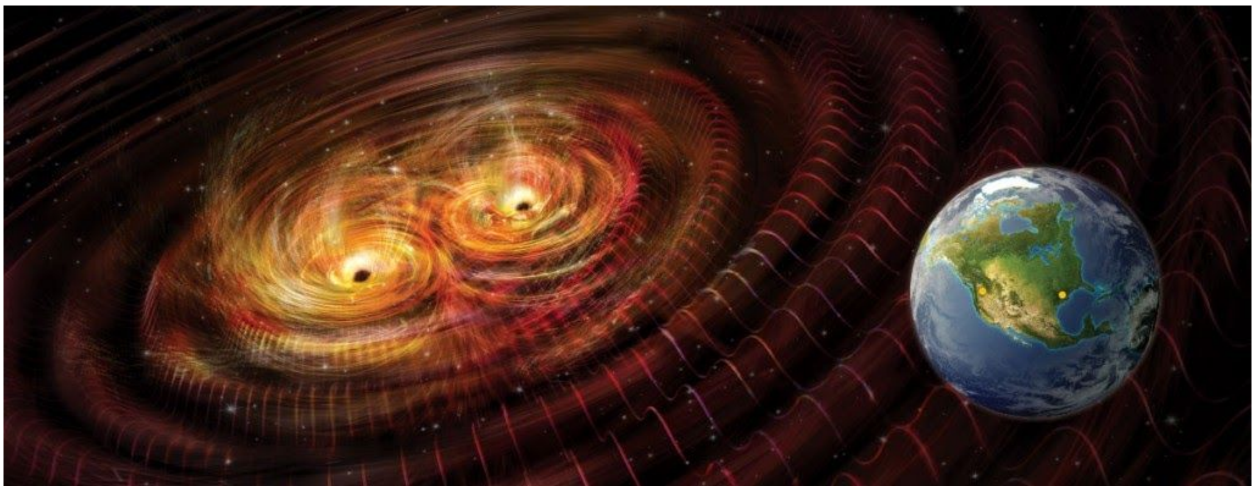

What phenomenon was observed?

- The phenomenon detected was the collision of two black holes.
- Using the world's most sophisticated detector, the scientists listened for 20 thousandths of a second as the two giant black holes circled around each other.
- At the beginning of the signal, their calculations told them how stars perish.
- The two objects had begun by circling each other 30 times a second.
- By the end of the 20 millisecond snatch of data, the two had accelerated to 250 times a second before the final collision and a dark, violent merger.
- The scientists detected this cataclysmic event using an instrument so sensitive it could detect a change in the distance between the solar system and the nearest star four light years away to the thickness of a human hair.
- It took just 20 milliseconds to catch the merger of two black holes, at a distance of 1.3 billion light years.

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What is India's Contribution?

- The Indian scientific community has made seminal contributions to gravitational-wave physics over the last couple of decades.
- The group at Bangalore led by B.R. Iyer (currently at International Centre for Theoretical Sciences (ICTS)-TIFR) in collaboration with a group of French scientists pioneered the theoretical calculations used to model gravitational-wave signals from orbiting black holes.
- In parallel, the group at Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune did foundational work on developing the data-analysis techniques used to detect these weak signals.
- The Indian participation in the LIGO Scientific Collaboration, under the umbrella of the **Indian Initiative in Gravitational-Wave Observations (IndIGO)**, includes scientists from Chennai Mathematical Institute, ICTS-TIFR Bangalore, IISER and IIT's, Institute for Plasma Research Gandhinagar, IUCAA Pune, Raja Ramanna Centre for Advanced Technology Indore and TIFR Mumbai.
- The ICTS-TIFR group made significant, direct contributions in obtaining estimates of the mass and spin of the final black hole, and the energy and peak power radiated in gravitational waves.
- The group has also contributed to the astrophysical **interpretation of the binary black hole merger.**
- The ICTS-TIFR group designed and implemented one of the tests of general relativity that have shown that the current observation is completely consistent with a binary black hole collision in Einstein's theory.

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Is Gravity waves different from gravitational waves?

- Yes, While both have gravity in common, gravity waves and gravitational waves are two **very different.**
- Gravity Waves are physical perturbations driven by the restoring force of gravity in a planetary environment.
- In other words, gravity waves are specific to planetary atmospheres and bodies of water.
- Let us understand this:

1. In the case of atmospherics, as air blows across an ocean and then encounters an island, for example, that air will be forced to rise.
2. Downwind from the island, the air will be forced to a lower altitude by gravity, but its buoyancy will work against gravity forcing it aloft again.
3. The result is often a region of oscillating air in the atmosphere that can produce clouds in the waves' crests (or highest points) as moisture from lower altitude condenses.Also, in the case of oceans, surface gravity waves form at the atmosphere/water interface
4. Wind blows the surface out of equilibrium causing the restoring force of gravity to force the surface back down, while the water's buoyancy pushes it back up.

5. Wind-driven waves, tides and tsunamis are all examples of gravity waves

What is interferometer and LIGO?

- Interferometers are investigative tools used in many fields of science and engineering.
- They are called interferometers because they work by merging two or more sources of light to create an interference pattern, which can be measured and analysed and hence "Interfere-ometer".
- The interference patterns generated by interferometers contain information about the object or phenomenon being studied.
- They are often used to make very small measurements that are not achievable any other way.
- They are so powerful for detecting gravitational waves-LIGO's interferometers are designed to measure a distance 1/10,000th the width of a proton!

What is LIGO?

- Laser Interferometer Gravitational-Wave Observatory (LIGO) is designed to open the field of gravitational-wave astrophysics through the **direct detection** of gravitational waves predicted by Einstein's General Theory of Relativity.
- LIGO's multi-kilometer-scale gravitational wave detectors use laser interferometry to measure the minute ripples in space-time caused by passing gravitational waves from cataclysmic cosmic sources.
- LIGO consists of two widely separated interferometers within the United States—one in Hanford, Washington and the other in Livingston, Louisiana—operated in unison to detect gravitational waves**.**